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THE INFLUENCE OF SEASONALITY AND SELECTED WEATHER VARIABLES ON AUTUMN MIGRATION OF THREE SPECIES OF HAWKS THROUGH THE CENTRAL APPALACHIANS

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Few studies have reported the magnitude of autumn hawk migration through the central Appalachians. DeGarmo (1953) conducted a 5-year study of autumn hawk migration through West Virginia, but his data included full-season coverage from only a single point. Robbins (1950) reported hawk-count results obtained on a single day from 13 major and minor ridges in Maryland.

The physiographic features and weather associated with the large concentrations of migrating hawks in the northern-middle Atlantic states are well documented (see review in Haugh 1972, Brett and Nagy 1973, Dunne and Clark 1977). Unique physiographic features are absent from the ridge and valley system of the central Appalachians, as are the large concentrations of hawks such as those seen at Hawk Mountain (Brett and Nagy 1973) and at coastline sites (Allen and Peterson 1936, Mueller and Berger 1961, Hofslund 1966, Haugh 1972, Alerstam 1978).

Our objectives were to evaluate the influence of seasonality and selected weather variables on autumn hawk migration at two look-outs in the central Appalachians. Univariate and multivariate procedures were employed (see Richardson 1978) to evaluate the data which were collected according to the format recommended by the Hawk Migration Association of North America.

METHODS

Watches were conducted at Dan's Rock (39°35′N, 78°53′W) (Dan's Mountain) 1975–1979, located on the eastern edge of the Allegheny Front in western Maryland, Allegany County, at 822 m elev., and at High Rock (39°32′N, 79°6′W), Garrett Co., on Big Savage Mountain, 1977–1979, at 912 m elev. High Rock is 19 km west of Dan's Rock. Both lookouts provide excellent visibility in all directions and it is unlikely that the same hawks were counted at both look-outs since all observations were of hawks moving southwest, parallel to the ridges. Fig. 1 shows the orientation of the ridge system for the region and the location of the two look-outs.

Data were recorded on the standard forms of the Hawk Migration Association of North America. Weather data were obtained at the beginning of each hour and included temperature, maximum horizontal visibility, wind speed, wind direction and percent cloud cover. Neither site was monitored for the entire period of migration. At Dan's Rock, most weekends from 1 September–14 November were monitored; in 1977 and 1978, weekday periods were also monitored. At High Rock and at Dan's Rock in 1979, 4-h time periods were chosen randomly for observation. We feel that a representative sample of all types of weather and migration volumes are proportionally correct with this protocol.

All statistical analyses were conducted using the Statistical Package for the Social Sciences (Nie et al. 1975). To reduce the degree of skewness, the hourly counts of the three dependent variables (number of Broad-winged Hawks [*Buteo platypterus*], Red-tailed Hawks [*B. jamaicensis*] and Sharp-shinned Hawks [*Accipiter striatus*]) were transformed using the natural logarithm + 1 (Richardson 1974, Alerstam 1978). The visibility variable was transformed with a square root function (Richardson 1974). No other independent variables were transformed; all had skewness and kurtosis values <1.5.

For analysis of weather variables, dates were chosen to encompass 95% of the typical migration period based on 5 years of observation (cf. Haugh 1972, Alerstam 1978). They were as follows: Broad-winged Hawk—1 September–4 October; Red-tailed Hawk—20 September–14 November; and for the Sharp-shinned Hawk—1 September–30 October.

Wilcoxon matched-pairs tests were conducted on five weather variables for which 57 h of simultaneous data existed at both ridges. The mean number of hawks migrating by each look-out was evaluated with Mann-Whitney U-tests to examine relative migration intensity at the two look-outs. A fixed effects, 2-way analysis of variance (ANOVA) was conducted to determine the possible interaction of wind speed and wind direction. Four wind speed categories (0–8, 9.6–16, 17.6–24, >25.6 km/h) were used. Wind direction was classified as either following or opposing (Richardson 1978). As the direction of migration was southwest, paralleling the ridges, winds from the south, southwest and west were considered as opposing winds, all other directions and calm–variable being considered following.

Examination of standardized error residuals from multiple regression showed strong autocorrelations in the data. The problem of error terms being serially correlated and failure to meet the appropriate levels of the Durbin-Watson test precluded the use of multiple regression techniques (Neter and Wasserman 1974, Richardson 1974). The data were analyzed using stepwise discriminant function analyses by reducing the dependent variable to a migration (≥ 1 hawk/h) vs no migration analysis. Other recent migration studies that have used discriminant analysis in a similar manner include Able (1973), Richardson (1974), Alterstam (1978) and Beason (1978). As used in this study, discriminant analysis has both a predictive and an explanatory function. An explanation of the association of the independent variables with migration is achieved by examining the sign of the correlation of the canonical discriminant functions with the observation variables (cf. Able 1973, Williams 1981). The predictive or classification portion of discriminant analysis allows examination of the strength of the linear discriminant functions in achieving group separation. The stepwise selection criteria used minimized Wilk's lambda and thereby maximized the between groups F-ratio. For the discriminant analyses wind direction was coded with tail winds at 0° scaling to perpendicular winds at 90° and opposing winds at 180°.

RESULTS

Table 1 includes the total number of hawks observed at Dan's Rock and High Rock and species percentages compared with those for Hawk Mountain, Berks and Schuykill counties, Pennsylvania. At all locations the Sharp-shinned, Red-tailed and Broad-winged hawks make up over 75% of the total counts. The seasonal cycle of fall migration for these three species is given in Fig. 2 for both look-outs pooled. The peak flights of Sharp-shinned Hawks were from 5–15 October, and for Red-tailed Hawks from 20–30 October. The Broad-winged Hawk attained peak flights between

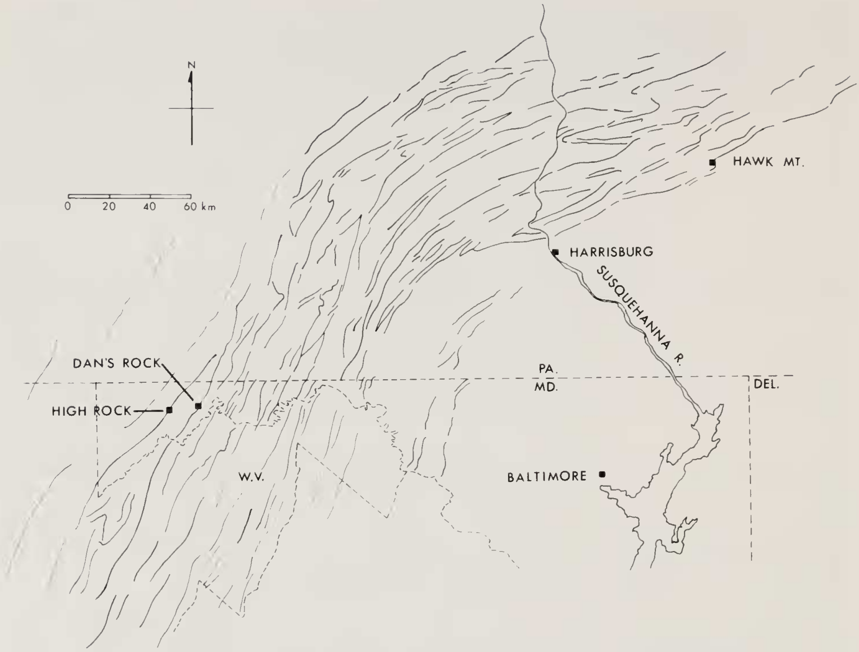

FIG. 1. The ridge system from eastern Pennsylvania southwest through West Virginia, including the two study sites in western Maryland.

15–25 September when 47% of the total flight occurred but a large drop-off in daily counts did not occur until after 30 September.

Results of the Mann-Whitney U-tests showed that the total number of hawks ($P < 0.001$), number of Red-tailed Hawks ($P < 0.01$), and number of Broad-winged Hawks ($P < 0.01$) were greater at Dan's Rock. No difference was found for the number of Sharp-shinned Hawks ($P > 0.05$). Comparing simultaneous weather data at the two look-outs revealed significant differences in visibility and temperature (both Wilcoxon matched-pairs test [$P < 0.01$]). Because of these differences, subsequent analyses treat each look-out separately.

The results of the 2-way ANOVA showed no interaction among the two wind directions and the four wind speed categories at High Rock for any of the three species ($P > 0.1$ in all cases). For the Broad-winged Hawk at High Rock winds >25 km/h had higher hourly counts based on Duncan's multiple range test (DMRT) (df = 3152, $P < 0.05$). Sharp-shinned Hawk flights at High Rock were greater when wind speeds were >9 km/h (DMRT) (df = 3197, $P < 0.05$). At Dan's Rock the only significant results

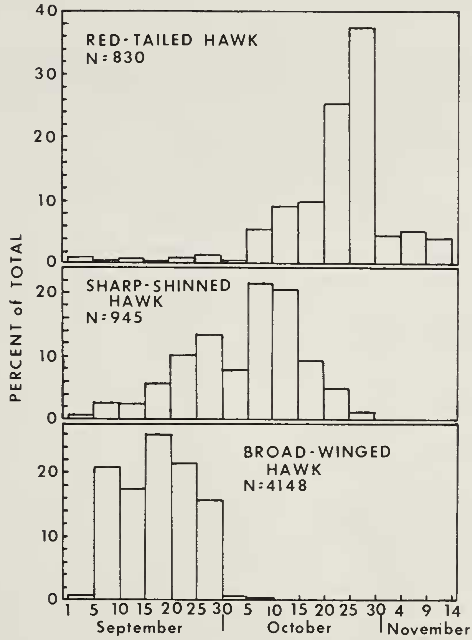

FIG. 2. Temporal distribution for three migrating hawk species at Dan's Rock and High Rock, Maryland, during the autumns of 1975–1979.

(df = 2462, $P < 0.01$) of the 2-way ANOVA were an interaction of wind speed and direction for the Broad-winged Hawk. Following winds >9 km/h had a higher number of Broad-winged Hawks/h (DMRT) ($P < 0.05$).

Three discriminant analyses were conducted on the Dan's Rock data (Table 2). For the Sharp-shinned Hawk the canonical correlation coefficient is low, even though the between groups F-statistic is significant. Migration tended to occur with following winds, good visibility and during later periods of the available migratory period. Classification was 26% above chance (Wiedemann and Fenster 1978) at Dan's Rock, and when the Dan's Rock discriminant function equation was used to predict migration at High Rock similar predictability was obtained. For the Broad-winged Hawk with a 35-day migratory period, migration tended to occur with strong following winds, good visibility, warm temperatures and during afternoon periods. Classification results were similar to those of the Sharp-shinned Hawk. The discriminant analysis of the Red-tailed Hawk data had a much higher canonical correlation and much better classification than for the other two species. The results revealed that migration tended to

TABLE 1
SUMMARY OF WESTERN MARYLAND FALL HAWK COUNTS AND SPECIES PERCENTAGES, INCLUDING HAWK MT., PENNSYLVANIA, 1975–1979

	Dan's Rock		High Rock		% of total	% of total for Hawk Mt.[a]
	1975–1979	%	1977–1979	%		
Accipiter gentilis (Goshawk)	4	0.07	0	0.00	0.05	0.33
A. striatus	641	10.90	311	20.59	12.89	15.45
A. cooperii (Cooper's Hawk)	86	1.46	25	1.66	1.50	0.75
Buteo jamaicensis	953	16.22	134	8.87	14.71	16.45
B. lineatus (Red-shouldered Hawk)	61	1.04	7	0.46	0.92	1.95
B. platypterus	3447	59.17	718	47.55	56.39	57.47
B. lagopus (Rough-legged Hawk)	2	0.03	0	0.00	0.03	0.06
Aquila chrysaetos (Golden Eagle)	7	0.12	0	0.00	0.09	0.22
Haliaeetus leucocephalus (Bald Eagle)	5	0.09	1	0.07	0.08	0.28
Circus cyaneus (Northern Harrier)	79	1.34	24	1.59	1.39	1.32
Pandion haliaetus (Osprey)	33	0.56	11	0.73	0.60	1.98
Falco peregrinus (Peregrine Falcon)	3	0.05	2	0.13	0.07	0.14
F. columbarius (Merlin)	2	0.03	0	0.00	0.03	0.12
F. sparverius (American Kestrel)	56	0.95	90	5.96	1.98	2.09
Unidentified	497	8.46	187	12.38	9.26	1.08
Total	5876	100.49	1510	99.99	99.99	99.69
Days	124	—	60	—	—	—

[a] From Haugh (1972) for 1954–1968.

occur when winds were opposing and light, visibility was good, temperature was high, cloud cover was low, and during later periods of the available migratory period.

DISCUSSION

The similarity of the species composition in western Maryland with that at Hawk Mountain suggests that these two sites are sampling similar interior migrant populations of hawks (see Nagy 1977). As lakes Erie and Ontario effectively shunt Canadian birds westward during the autumn migration (Haugh 1972), western Maryland flights probably represent birds that have entered the ridge and valley system in Pennsylvania only from points north and east.

The peak flights of Sharp-shinned Hawks at our sites coincided with that of Hawk Mountain (see Haugh 1972). At both locations a noticeable drop-off in flights occurred after 15 October. Peak flights of Red-tailed Hawks also exhibited a temporal similarity. The Broad-winged Hawk exhibited a different pattern in western Maryland from that of Hawk Mountain. The peak at Hawk Mountain was from 10–19 September, when about

TABLE 2

RESULTS OF DISCRIMINANT ANALYSES FOR NO MIGRATION COMPARED WITH MIGRATION ACCORDING TO SELECTED VARIABLES AT DAN'S ROCK, MARYLAND, 1975–1979

	Sharp-shinned Hawk		Broad-winged Hawk		Red-tailed Hawk	
	Sign of correction with migration[a]	P^{b}	Sign of correction with migration	P	Sign of correction with migration	P
Wind direction	–	***	–	***	+	***
Wind speed	—	NS	+	**	–	***
Visibility	+	***	+	***	+	***
Temperature	—	NS	+	***	+	***
% cloud cover	—	NS	—	NS	–	***
Julian day (day of year)	+	***	—	NS	+	***
Hour	—	NS	+	***	—	NS
F-statistic	6.8	***	5.1	***	30.9	***
Number of hours	309	—	240	—	250	—
Canonical correction coeff.	0.250	—	0.313	—	0.658	—
% correct classification	63%	—	62%	—	86%	—
Cohen's Kappa (Kw)[c]	26%	—	23%	—	70%	—
% correct classification for High Rock	63%	—	66%	—	69%	—
Cohen's Kappa (Kw)	29%	—	26%	—	25%	—

[a] The sign of the pooled-within groups correlated between the canonical discriminant function and the discrimination variables. All signs are standardized.

[b] Levels of significance are as follows: $*P < 0.05$; $**P < 0.01$; $***P < 0.001$.

[c] A chance corrected classification statistic (see Wiedemann and Fenster 1978).

75% of the Broad-winged Hawks migrated by, while in western Maryland only 42% had migrated by then. Thus, while the flights of Broad-winged Hawks dropped off greatly after 20 September at Hawk Mountain (Haugh 1972), in western Maryland moderate flights continued until the end of September.

The leading lines (topographical features that induce migrating birds to follow them [Mueller and Berger 1967a]) of the central Appalachians are probably quite important for migrating hawks because the ridges are long and prominent. The eastern edge of the Allegheny Front (Dan's Mountain) seems to be a major leading line through this portion of the Appalachians. Although High Rock is at a slightly higher elevation than Dan's Rock, the vertical drop of the eastern edge of the Allegheny Front is much greater, perhaps providing greater lift and a stronger leading line for concentrating hawks (Richardson 1978). This is consistent with Mueller and Berger's (1967a) views on the effectiveness of a leading line. Sharp-shinned Hawks, which did not migrate in higher numbers at Dan's Rock, may not require the greater lift provided by the Allegheny Front. Less prominent ridges have a correspondingly smaller hawk flight based on a few days when lower elevation ridges to the east were monitored concurrently with Dan's Rock. Robbins (1950) found similar results based on his sampling of western Maryland ridges.

Mueller and Berger (1967b) found that the largest flights of Sharp-shinned Hawks occurred on strong westerly winds. No interaction between wind speed and direction was found in this study for Sharp-shinned Hawks although at High Rock wind speeds >9 km/h had higher hourly counts. The discriminant analysis for this species provided little predictability. The highest loading was on Julian day, indicating that the day of the season alone was the best predicting variable. For the Broad-winged Hawk the discriminant analysis results also showed low predictability. The highest canonical correlation coefficient and the highest percent correct classification was for the Red-tailed Hawk. Unlike the westerly wind component which produced peak hawk counts in many studies (see review in Richardson 1978) opposing winds and a southeasterly flow with clear, calm weather resulted in peak Red-tailed Hawk counts.

Few multivariate studies are available on hawk migration for comparison. Alerstam (1978), using stepwise discriminant analysis, had canonical correlation coefficients ranging from 0.48–0.60 when attempting to predict autumn hawk migration intensity at Falsterbo, Sweden. With over 30 variables, Beason (1978) was able to classify autumn water bird migration versus no migration with 80% correct classification while with only three variables, classification was 69% and Julian day was the important discriminating variable.

The results of this study seem to show that weather variables measured according to standard format (Hawk Migration Association of North America) have a low, but significant, predictive ability. Seasonality (Julian day) is probably the major predicting variable in determining the magnitude of autumn hawk migration in the central Appalachians, and the hour of the day apparently also influences migration patterns. Discriminant analysis, with only two groups, clarifies these points in a more simplistic manner than would multiple regression (Richardson 1974, 1978). Future researchers analyzing standardized HMANA data should compensate for the seasonality of migration (Richardson 1978).

SUMMARY

We compared the possible effects of weather, seasonality and topography on autumn hawk migration at two look-outs in the central Appalachians. Dan's Rock, located on the more prominent Allegheny Front, had more Red-tailed (*Buteo jamaicensis*) and Broad-winged (*B. platypterus*) hawks per hour than High Rock. The species composition of the flights was similar to those at Hawk Mountain, Pennsylvania.

For Sharp-shinned Hawks (*Accipiter striatus*), migration was associated with good visibility and following winds. Broad-winged Hawk migration was associated with good visibility, strong favorable winds, high temperatures and afternoon periods. Red-tailed Hawk migration was associated with light, opposing winds, characterized by southeasterly flows.

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